BTeV-doc 762

BTeV: Overview, Status, and Prospects

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What is BTeV?

- At the Tevatron p-$\bar{p}$ collider, at Fermilab:
  - Forward spectrometer.
  - Beauty and charm physics:
    - Precision measurements.
    - Exhaustive search for new physics.
- BTeV is a part of broad program to address fundamental questions in flavor physics.
- Details at: http://www-btev.fnal.gov
  - 4 talks at Beauty02: Kutschke(2), Butler, Newsom.

Fundamental Questions in Flavor Physics

- Why families? Why 3?
- Quark mixing angles: Are they explained by Standard Model (SM)? Arise from new physics?
- Mass heirarchy: Why? Related to mixing angles?
- Is CPT violated? If so, what physics is behind it?
- Matter/anti-matter asymmetry of the universe: What interactions were involved?
- Quarks vs leptons: What are the similarities and differences in mass heirarchies and mixing angles?

Fundamental Questions in Flavor Physics …

- These are interesting, compelling, questions which we must answer.
- The program to answer these questions involves present and future experiments in K, D, B, and neutrino physics and in astrophysics.
- BTeV is a crucial part of this program.

Physics Goals

- Measure: CP violation in $B_{(uds)}$, B_s mixing, rare b decay rates, CP violation and rare decays in the charm sector.
  - *J. Ellis: "My personal interest in CP violation is driven by the search for physics beyond the Standard Model…"*
  - We feel that way about all of the BTeV Physics program.
- Look for rare/forbidden decays discover new physics.
- Make an exhaustive search for physics beyond SM and to precisely measure SM parameters.
- Test for inconsistencies in the Standard Model: If found go beyond the SM and elucidate the new physics.

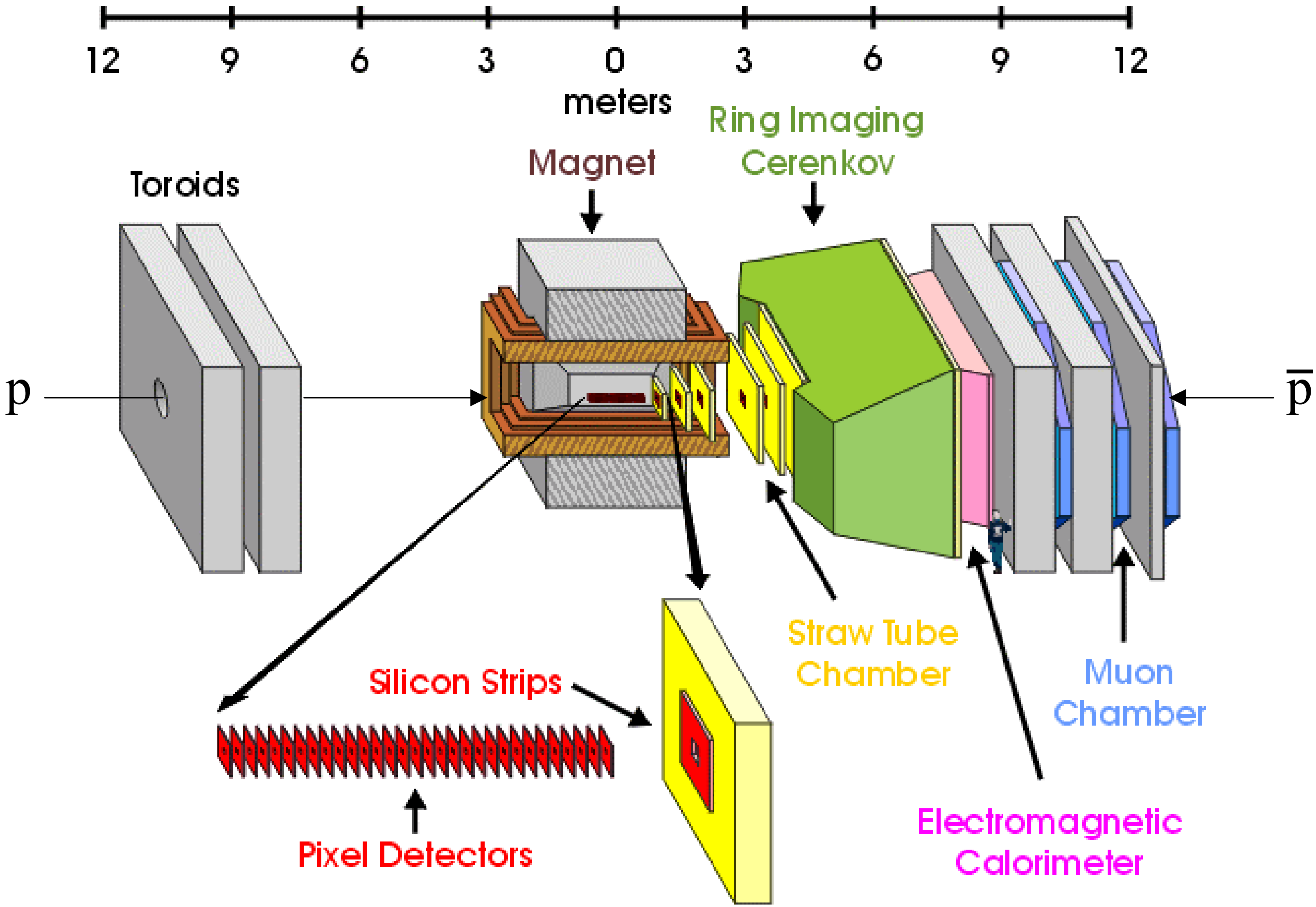
A Brief History of BTeV

- January 1999: R&D program approved by lab.
- June 2000: Stage I approval from lab.
  - Two arm spectrometer.
- Fall 2001: funding situation deteriorated.
  - Lab asked for a proposal for a descoped detector.
  - IR to reuse components from completed CDF/D0.
- May 2002: Stage I approval for descoped detector.
  - Instrument only one arm, at least initially.
  - PAC recommended lab explore other IR solutions.
  - Offline computed to be supplied via universities (grid).
  - Cost reduced about $70M to about $110M.

Peering into the Future

- Fall 2002: Fermilab internal cost/schedule review.
- Fall 2002: "P5 type" DOE review.
  - Key to obtaining large scale funding.
- Spring 2003: Lehman baseline review.
- FY 2004-2008: Construction funding.
  - Install test components early to get real experience.
  - Exploring staged installation to get some components in early and to allow early commissioning.
- 2008: Start of physics running.

BTeV Detector Layout



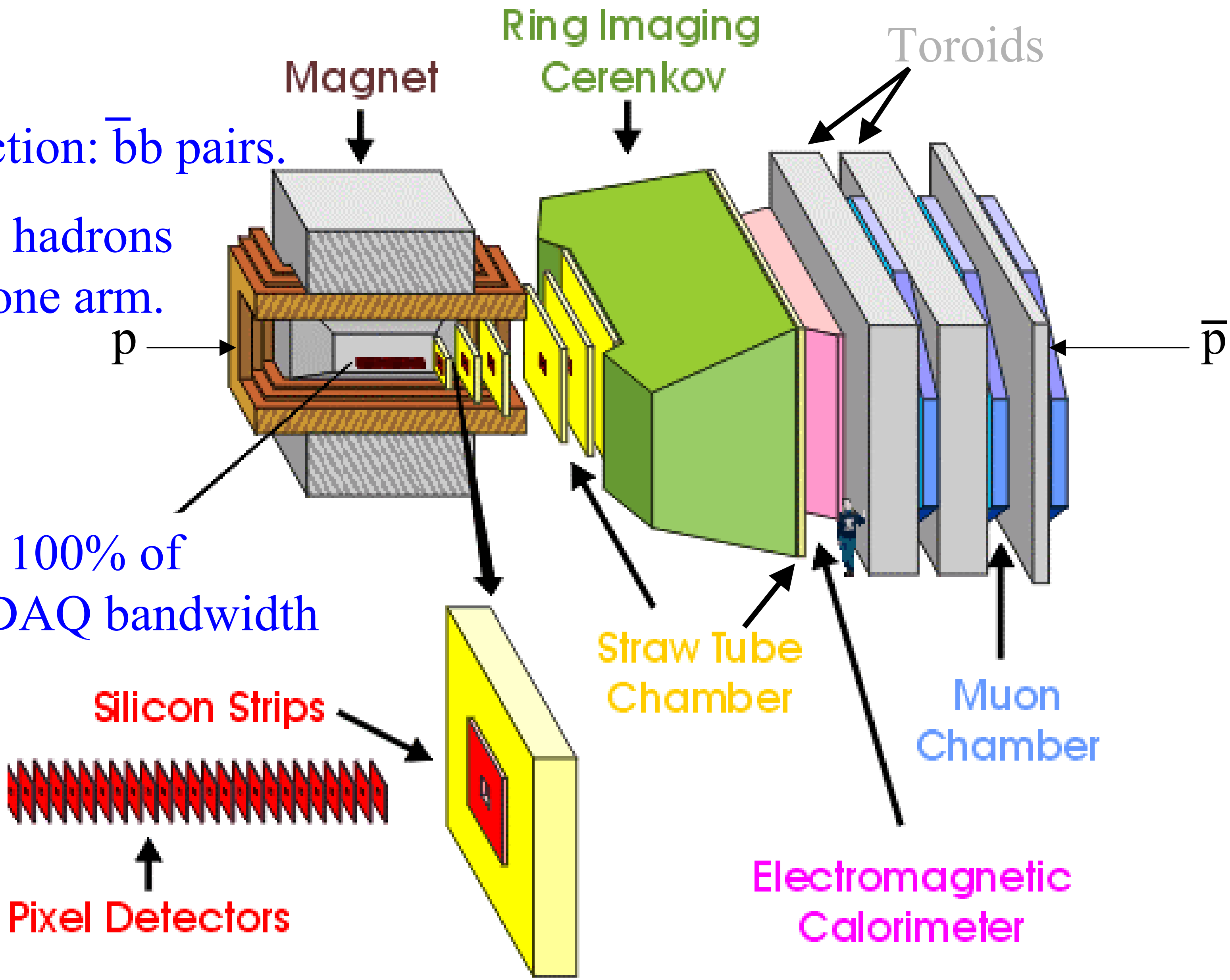
The "One Arm" Configuration

- The full vertex detector:
  - Covers the full length of IR.
  - Level 1 trigger: finds tracks in both z hemispheres to ensure the best primary vertex.
- 1 each: fwd tracking, RICH, EMCal, μ systems.
- The steel for the muon toroid on the un-instrumented side:
  - Shielding; support the compensating dipole; keep floor loading constant in case we instrument the other arm.
- We retain the full trigger and DA bandwidth.
  - Original estimate was conservative.
  - See discussion of offline computing …

• Production: $\bar{b}b$ pairs.

• Both b hadrons go into one arm.

• Retain 100% of trigger/DAQ bandwidth



Key Design Features of BTeV

- Magnet on the IR
  - Allows momentum measurement in the trigger.
- Precision vertex detector
  - Planar pixel arrays.
- Vertex trigger at Level 1.
  - Can trigger on final states with only hadrons.
- $PbWO_4$ Calorimeter
  - γ and π^0 reconstruction.
- Strong Particle ID
  - Ring Imaging Cerenkov (RICH) detector.
  - Hadron and lepton ID!
  - Background rejection.
  - Flavor tagging.
- Excellent muon ID system
  - Redundant triggering of final states with muons.
- Fast, high capacity DAQ.
  - Can record a significant fraction of all B decays.

Design Improvement Since Proposal

- RICH requires two radiators to cover full momentum range: Original: C_4F_{10} aerogel.
- Further study showed that aerogel will not work well enough: too few photons; lost in gas rings.
- Replaced aerogel with liquid C_5F_{12} radiator.
  - Gives significant ID power at low momentum.
- RICH has significant power to ID e and μ:
  - We now include this in our reach estimates.
- See my talk at this workshop on Thur. afternoon:
  - BTeV: Lepton, Hadron and Photon ID

Nominal Tevatron Parameters

Parameter	Value
Center of Mass Energy	2 TeV
Peak Instantaneous Luminosity	2×10^{32} cm^{-2} s^{-1}
Yearly Integrated Luminosity	2 fb^{-1}/year
Bunch spacing	132 ns
Luminous region (σ_x,σ_y,σ_z)	(0.003, 0.003, 30.) cm

- Physics reach estimates are quoted for one Snowmass year (10^7 s) of running at these parameters.
  - Exception: α using $B^0 \rightarrow \rho\pi \rightarrow \pi^+\pi^-\pi^0$ is two years.

Flavor Tagging

- $\varepsilon \equiv$ efficiency
- $D \equiv$ Dilution $\equiv (N_{right}-N_{wrong})/(N_{right}+N_{wrong})$
- Effective tagging efficiency $\equiv \varepsilon D^2$
- Recent extensive study uses:
  - Opposite side $K^{\pm}$ and leptons.
  - Opposite side Jet Charge.
  - Same side $\pi^{\pm}$ (for B^o) or $K^{\pm}$ for (B_s).
  - Poll methods in order of decreasing dilution.
- Conclusion: $\varepsilon D^2\,(B^o) = 0.10$, $\varepsilon D^2\,(B_s) = 0.13$, difference due to same side tagging.

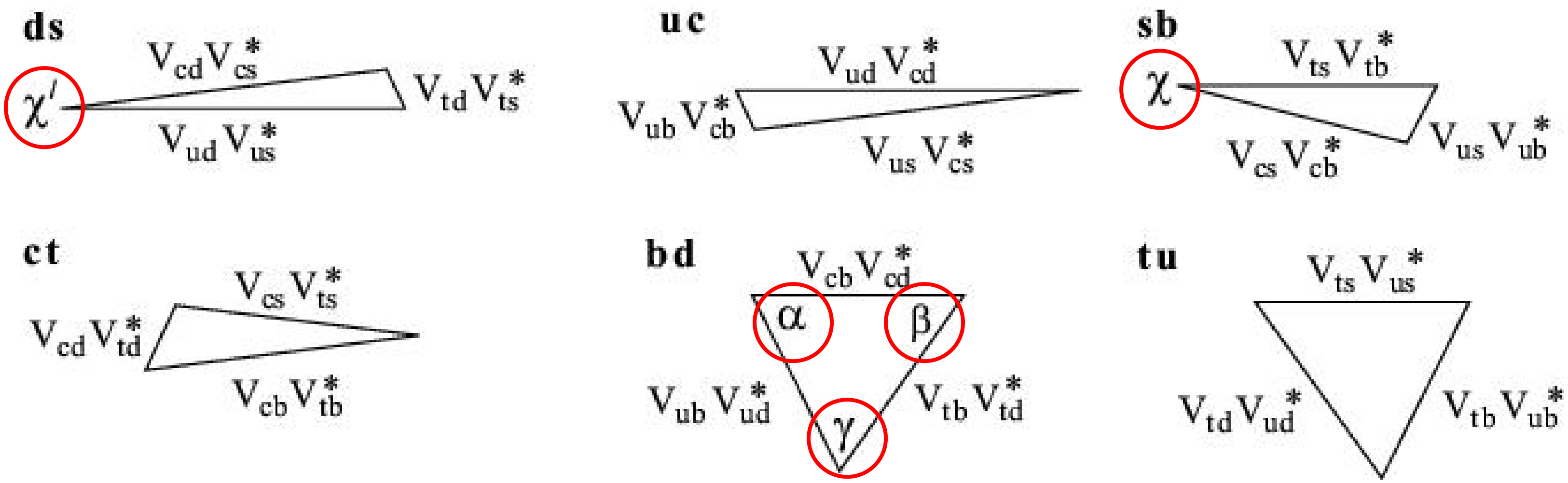
CP Violation CKM Physics and all That

Formulation of CKM Matrix

$$
V = \begin{array}{c c}
 & \begin{array}{ccc} d & s & b \end{array} \\
\begin{array}{c} u \\ c \\ t \end{array} &
\begin{pmatrix}
1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3\left(\rho - i\eta\left(1-\frac{1}{2}\lambda^2\right)\right) \\
-\lambda & 1-\frac{1}{2}\lambda^2 - i\eta A^2\lambda^4 & A\lambda^2\left(1+i\eta\lambda^2\right) \\
A\lambda^3\left(1-\rho-i\eta\right) & -A\lambda^2 & 1
\end{pmatrix}
\end{array}
$$

- Good λ^3 in real part & λ^5 in imaginary part.
- We know $\lambda=0.22$, $A\sim0.8$; constraints on ρ & η.

The 6 CKM Unitarity Triangles



$$\beta = \arg\left(-\frac{V_{tb}V_{td}^*}{V_{cb}V_{cd}^*}\right) \qquad \chi = \arg\left(-\frac{V_{cs}^*V_{cb}}{V_{ts}^*V_{tb}}\right)$$

$$\gamma = \arg\left(-\frac{V_{ub}^*V_{ud}}{V_{cb}^*V_{cd}}\right) \qquad \chi' = \arg\left(-\frac{V_{ud}^*V_{us}}{V_{cd}^*V_{cs}}\right) \qquad \alpha = \pi-(\beta+\gamma)$$

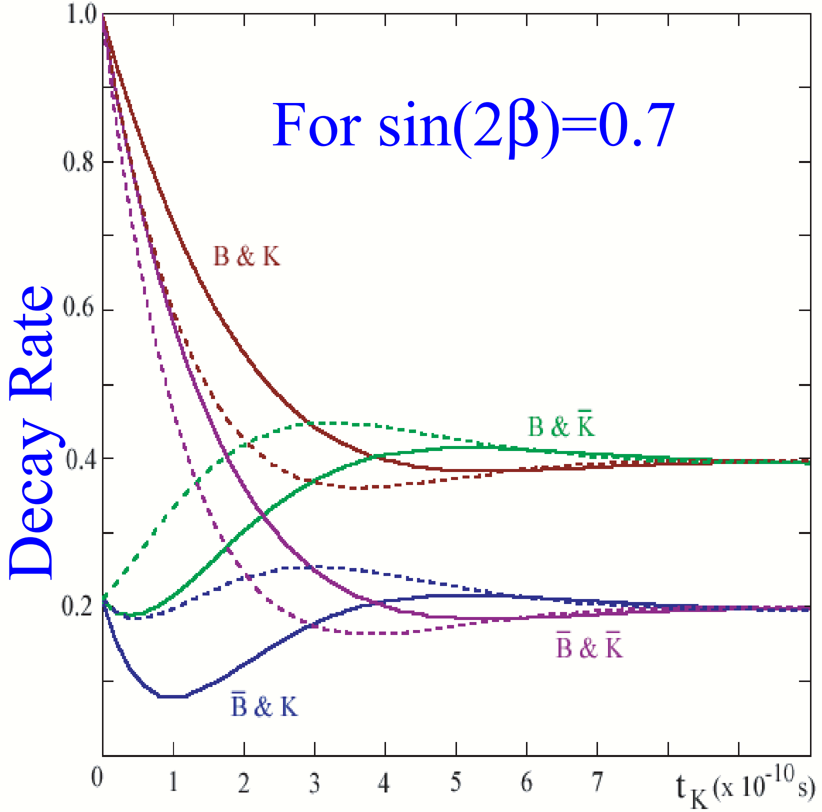
α, β & γ probably large, $\chi\sim 0.03$, χ' smaller

Measuring β

- $\sin(2\beta)$ has already been shown to be non-zero.
  - First hints CDF. Best measurements BaBar/Belle.
- We presume that $\sin(2\beta)$ will be well measured before BTeV starts running.
- BTeV should still be able to improve the measurement.
- Sensitivity $\sin(2\beta)$ using $B^o \rightarrow J/\psi\, K_s$ only in one year of running : $\pm$ 0.017.

Removing Ambiguities from β

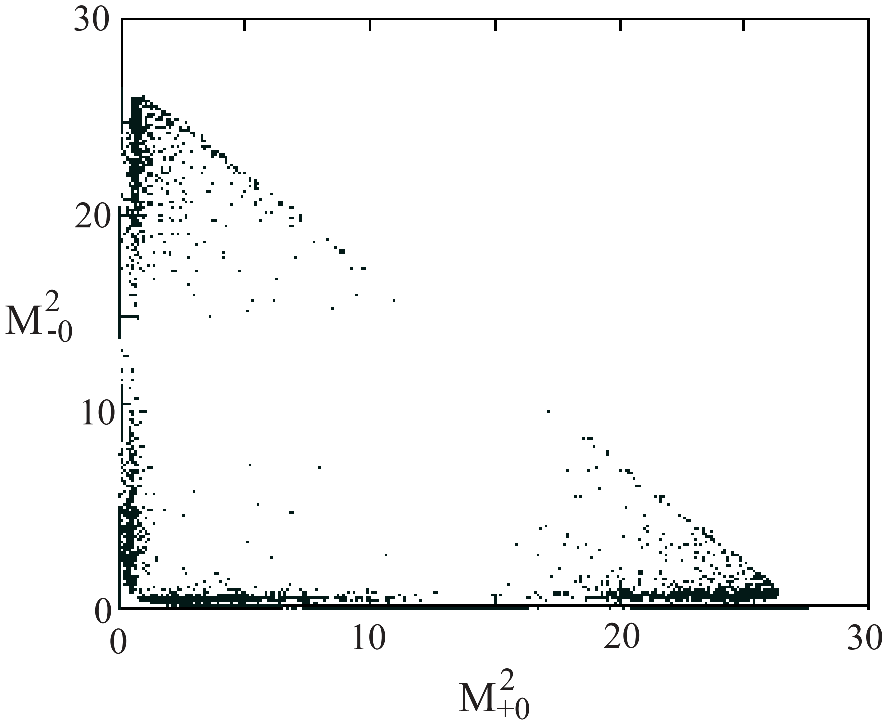
- $B^o \rightarrow \psi K^o$, $K^o \rightarrow \pi^+ \ell^- \nu$
- Exploits K^0_{S}/K^0_{L} interference.
  - Equal amplitudes to $\pi^+ \ell^- \nu$.
- Low yield:
  - $\approx$1/100 of $K_s \rightarrow \pi^+\pi^-$.
  - $\approx$1700/year (untagged)
- Can determine sign of β with O(100) low background, tagged events.
- Sensitivity improves for smalle sin(2β).



t_K integrated over t_B

Measuring α

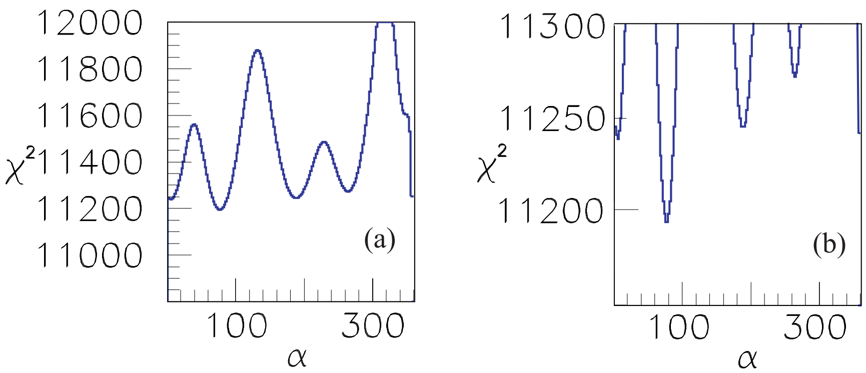
- $B^0 \to \pi^+\pi^-$:
  - Sensitivity to A_{CP} in one year: ± 0.030
  - But penguin pollution!
  - Need $\pi^-\pi^0$ and $\pi^0\pi^0$ to unpollute. Tough to do!
- $B^0 \to \rho\pi \to \pi^+\pi^-\pi^0$
  - Dalitz plot analysis (Snyder and Quinn).
    - (next page)



- Sensitive to both $\sin(2\alpha)$ and $\cos(2\alpha)$.

Mini MC Study of $B^0 \rightarrow \rho\pi \rightarrow \pi^+\pi^-\pi^0$

- Dalitz plot density:
  - Synder Quinn matrix element.
  - Incoherent BG: S:BG = 4:1.
    - Non-resonant (flat).
    - Resonant in ρ.
- Acceptance and smearing parameterized from Geant based study.
- Results for trials of 1000 signal events + BG.
- Sensitivity (two years) < 4°.



α (gen)	R_{res}	R_{non}	α (recon)	δα
77.3°	0.2	0.2	77.2°	1.6°
77.3°	0.4	0	77.1°	1.8°
93.0°	0.2	0.2	93.3°	1.9°
93.0°	0.4	0	93.3°	2.1°
111.0°	0.2	0.2	111.7°	3.9°
111.0°	0.4	0.2	110.4°	4.3°

Four Ways of Measuring γ

Model independent

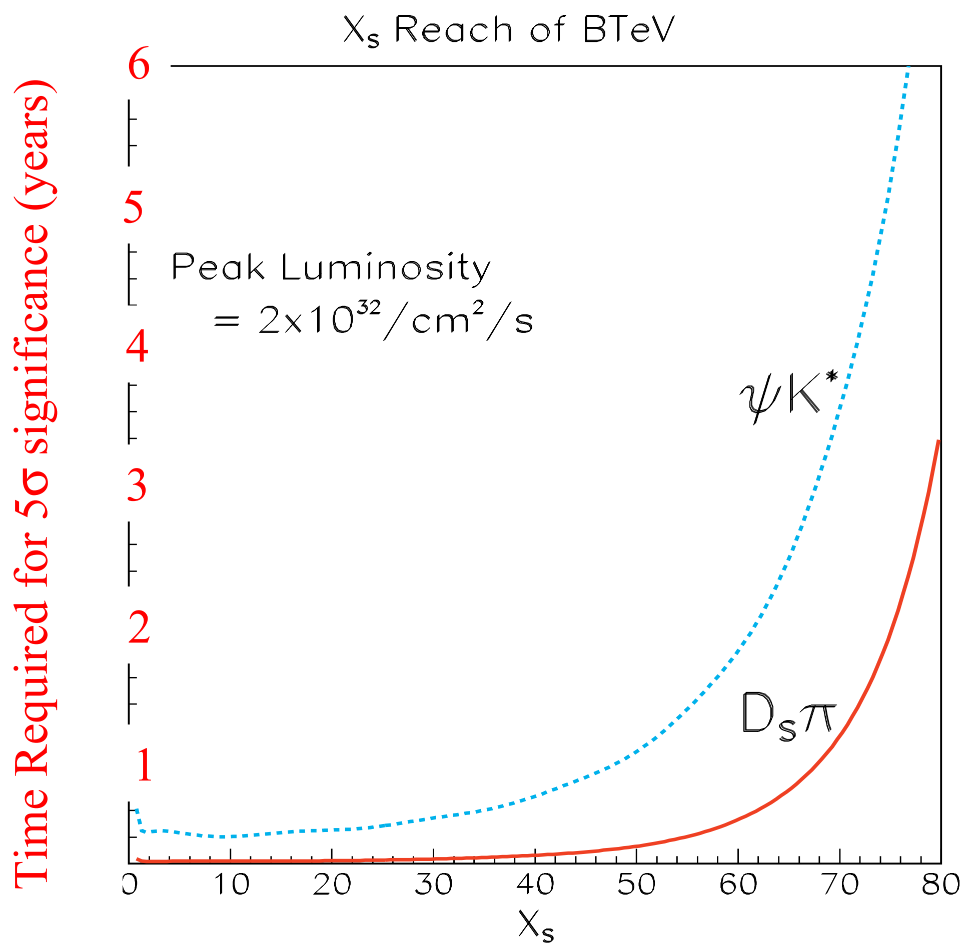
- Time dependent flavor tagged analysis of $B_s \to D_s K^-$.
  - Sensitivity in one year: $\pm 8^o$
- Rate difference between $B^- \to D^o K^-$ & $B^+ \to D^o K^+$.
  - Sensitivity in one year: $\pm 13^o$
- Rate measurements in $K^o \pi^\pm$ and $K^\pm \pi^\mp$ (Fleisher-Mannel) or rates in $K^o \pi^\pm$ & asymmetry in $K^\pm \pi^o$ (Neubert et al) .
  - Sensitivity in one year: $\pm 4^o$ + Theory uncertainties.
- Use U spin symmetry d$\Leftrightarrow$s: measure time dependent asymmetries in both $B^o \to \pi^+ \pi^-$ & $B_s \to K^+ K^-$ (Fleischer)

Measuring χ

- $B_s \to J/\psi\ \eta$ and $B_s \to J/\psi\ \eta'$.
  - $\psi \to l^+ l^-$
  - We now use both electrons and muons.
- This measurement is possible because of the excellent photon and π^0 detection provided by the $PbWO_4$ calorimeter.
- Excellent S/B: 15:1 for η and 30:1 for η'.
- Sensitivity for one years running: ± 0.024.
- Will take several years to resolve expected: $\chi \approx 0.03$.

x_s Reach

- If x_s is less than about 70, BTeV will be able to measure it in about 1 year.
- If it is less than about 80, BTeV will be able to measure it in about 3.2 years.



Physics Beyond the Standard Model

- New Physics (NP) effects can be subtle:
  - More than just: $\alpha + \beta + \gamma \neq 180^o$.
- Suppose there is NP in B^0 mixing:
  - If we measure β and α via mixing mediated modes, $J/\psi K^0_S$ and $\pi^+\pi^-$, we may measure:
    - $2\beta' = 2\beta + \theta$
    - $2\alpha' = 2\alpha - \theta$
  - And measure γ via a non mixing method.
  - $\alpha' + \beta' + \gamma = \alpha + \beta + \gamma = 180^o$
  - The triangle closure test misses this sort of NP.
- We need to be careful when we do this!

Generic Tests for New Physics

- Specific decays, non-specific models
  - $B \to K\ell^+\ell^-$ & $B \to K^*\ell^+\ell^-$: can observe NP in distribution of $M(\ell^+\ell^-)$ and Dalitz plot is sensitive to subtle interference effects. See hep-ph/9408382.

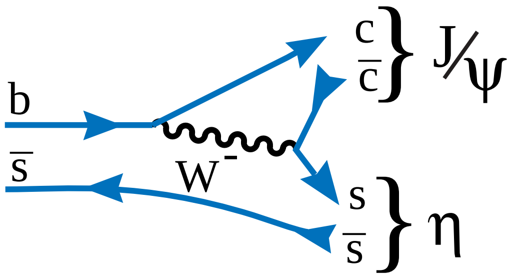
Reaction	B(10^{-6})	Yield/year	S/B
$B \to K^*\mu^+\mu^-$	1.5	2530	11
$B \to K\mu^+\mu^-$	0.4	1470	3.2
$b \to s\, \mu^+\mu^-$	5.7	4140	0.13

- Check for inconsistencies in SM without reference to a particular model.

Critical Checks using χ

- Silva & Wolfenstein (hep-ph/9610208), (Aleksan, Kayser & London):
  - Measure χ using $B_s \to J/\psi\eta^{(\prime)}$, $\eta \to \gamma\gamma$, $\eta' \to \rho\gamma$.
    - Can also use $J/\psi\phi$, but need a complicated angular analysis.
  - The critical check is:

$$\sin\chi = \lambda^2 \frac{\sin\beta\sin\gamma}{\sin(\beta+\gamma)}$$



  - Very sensitive since $\lambda = 0.2205 \pm 0.0018$
  - Since $\chi \sim 0.03$, need lots of data.
  - Sensitivity to χ for one years running: ± 0.024.

Survey of New Physics Sensitivities

- See the BTeV “Proposal Update” for a discussion of how many NP ideas can be tested in B decay.
  - MSSM and othe SUSY variants
  - Left-Right Symmetric models
  - 2 Higgs doublet models
  - Extra d type single quarks.
  - FCNC couplings of the Z.
  - Non-commutative geometries
  - Mixing with a 4^{th} generation.
  - Extra dimensions

Tests for New Physics (Nir, hep-ph/9911321)

- Suppose NP in B^o mixing, θ_D , B^o decay, θ_A, D^o mixing, $\phi_{K\pi}$.

Model	$d_N/10^{-25}$	θ_D	θ_A	$asy_{D\to K\pi}$
SM	10^{-6}	0	0	0
Approximate Universality	10^{-2}	O(0.2)	O(1)	0
Alignment	10^{-3}	O(0.2)	O(1)	O(1)
Heavy squarks	$\sim 10^{-1}$	O(1)	O(1)	$O(10^{-2})$
~~Approx. CP~~	$\cancel{\sim 10^{-1}}$	$\cancel{-\beta}$	$\cancel{0}$	$\cancel{O(10^{-3})}$

- Specific pattern in each model ⇒ways of distinguishing models.

Summary of New Physics

- Using b and c decays mediated by loop diagrams BTeV is sensitive to mass scales of up to few TeV.
- The New Physics effects in these loops may be the <u>only</u> way to distinguish among models.
- Masiero & Vives: *"the relevance of SUSY searches in rare processes is not confined to the usually quoted possibility that indirect searches can arrive 'first' in signaling the presence of SUSY. Even after the possible direct observation of SUSY particles, the importance of FCNC & CPV in testing SUSY remains of utmost relevance. They are & will be complementary to the Tevatron & LHC establishing low energy supersymmetry as the response to the electroweak breaking puzzle"* (hep-ph/0104027)
- We agree, except we would replace "SUSY" with "New Physics"

Comparison with LHC-b

- Advantages of LHCb
  - 5× higher b cross-section; 1.6× higher σ_b/σ_{tot}.
- Advantages of BTeV
  - Detached vertex trigger at level 1.
    - Enabling technologies:
      - Magnet on the IR: we can reject low p tracks at level 1.
      - Pixels: very low occupancy, only 6mm from beam (cf 1 cm).
    - Allows us to trigger on very general properties of b's.
  - $PbWO_4$ Ecal with CLEO/BaBar/Belle-like performance.
  - Trigger/DA design lets us read out 5× as many b's/second.

Comments on the e^+e^- Super B-Factories

- At the $\Upsilon(4S)$, it would take a $10^{36}/cm^2/s$ e^+e^- collider to match the performance of BTeV for B^o & $B^\pm$.
- There would be no competition on B_s, Λ_b, …
- KEK is only proposing $10^{35}/cm^2/s$.
- For Super-BaBar there are serious technical problems for both the machine & the detector.
- We believe the cost will far exceed that of BTeV. Recent HEPAP subpanel mentions $500M.

Summary and Conclusions

- The Fermilab director has given Stage I approval to a revised proposal to run BTeV with only one arm fully instrumented.
- In the RICH detector, the aerogel radiator has been replaced with liquid C_5F_{12}.
- We have learned use the RICH for lepton ID:
  - Single(double) lepton ID efficiency up $\times 2.4$ ($\times 3.9$).
- The reduced scope BTeV remains an excellent detector and will be a leader in b and c physics in the last half of this decade.

Summary of CKM Physics Reach (10^7 s)

Reaction	$\mathcal{B}$(B)(x10^{-6})	# of Events	S/B	Parameter	Error or (Value)
$B^o \to \pi^+\pi^-$	4.5	14,600	3	Asymmetry	0.030
$B_s \to D_s K^-$	300	7500	7	γ	8^o
$B^o \to J/\psi K_S$, $J/\psi \to l^+ l^-$	445	168,000	10	sin(2β)	0.017
$B_s \to D_s \pi^-$	3000	59,000	3	x_s	(75)
$B^- \to D^o (K^+\pi^-) K^-$ $B^- \to D^o (K^+K^-) K^-$	0.17 1.1	170 1,000	1 >10	γ	13^o
$B^- \to K_S \pi^-$ $B^o \to K^+\pi^-$	12.1 18.8	4,600 62,100	1 20	γ	$<4^o$ + theory errors
$B^o \to \rho^+\pi^-$ $B^o \to \rho^o\pi^o$	28 5	5,400 780	4.1 0.3	α	$\sim 4^o$
$B_s \to J/\psi\, \eta$, $B_s \to J/\psi\, \eta'$ $J/\psi \to l^+l^-$	330 670	2,800 9,800	15 30	χ	0.024

Backup Slides

Specific Comparisons with LHC-b

Mode	BR	BTeV Yield	BTeV S/B	LHC-b Yield	LHC-b S/B
$B_s \rightarrow D_s K^-$	3.0×10^{-4}	7530	7	7660	7
$B^o \rightarrow \rho^+ \pi^-$	2.8×10^{-5}	5400	4.1	2140	0.8
$B^o \rightarrow \rho^o \pi^o$	0.5×10^{-5}	776	0.3	880	not known

Comparisons With Current e^+e^- B factories

- Number of flavor tagged $B^o \rightarrow \pi^+ \pi^-$ ($\mathcal{B}=0.45\times10^{-5}$)

	$\mathcal{L}$ ($cm^{-2}s^{-1}$)	σ	$\#B^o/10^7 s$	ε	εD^2	#tagged
e^+e^-	10^{34}	1.1 nb	1.1×10^8	0.45	0.26	56
BTeV	2×10^{32}	100μb	1.5×10^{11}	0.021	0.1	1426

- Number of $B^- \rightarrow \overline{D}^o K^-$ (Full product $\mathcal{B}=1.7\times10^{-7}$)

	$\mathcal{L}$($cm^{-2}s^{-1}$)	σ	$\#B^o/10^7 s$	ε	#
e^+e^-	10^{34}	1.1 nb	1.1×10^8	0.4	5
BTeV	2×10^{32}	100μb	1.5×10^{11}	0.007	176

- B_s , B_c and Λ_b not done at Y(4S) e^+e^- machines

Reconstructed Events in New Physics Modes: Comparison of BTeV with B-factories

Mode	BTeV (10^7s)			B-fact (500 fb^{-1})		
	Yield	Tagged	S/B	Yield	Tagged	S/B
$B_s \to J/\psi \eta^{(\prime)}$	12650	1645	>15	-	-	
$B^- \to \phi K^-$	11000	11000	>10	700	700	4
$B^o \to \phi K_s$	2000	200	5.2	250	75	4
$B^o \to K^* \mu^+ \mu^-$	2530	2530	11	~50	~50	3
$B_s \to \mu^+ \mu^-$	6	0.7	>15	0		
$B^o \to \mu^+ \mu^-$	1	0.1	>10	0		
$D^{*+} \to \pi^+ D^o$, $D^o \to K\pi^+$	$\sim 10^8$	$\sim 10^8$	large	8×10^5	8×10^5	large

Summary of Required Measurements for CKM Tests

Physics Quantity	Decay Mode	Vertex Trigger	K/π sep	γ det	Decay time σ
$\sin(2\alpha)$	$B^o \to \rho\pi \to \pi^+\pi^-\pi^o$	✓	✓	✓	
$\sin(2\alpha)$	$B^o \to \pi^+\pi^-$ & $B_s \to K^+K^-$	✓	✓		✓
$\cos(2\alpha)$	$B^o \to \rho\pi \to \pi^+\pi^-\pi^o$	✓	✓	✓	
$\mathrm{sign}(\sin(2\alpha))$	$B^o \to \rho\pi$ & $B^o \to \pi^+\pi^-$	✓	✓	✓	
$\sin(\gamma)$	$B_s \to D_s K^-$	✓	✓		✓
$\sin(\gamma)$	$B^o \to D^o K^-$	✓	✓		
$\sin(\gamma)$	$B \to K \pi$	✓	✓	✓	
$\sin(2\chi)$	$B_s \to J/\psi\eta'$, $J/\psi\eta$		✓	✓	✓
$\sin(2\beta)$	$B^o \to J/\psi K_s$				
$\cos(2\beta)$	$B^o \to J/\psi K^*$ & $B_s \to J/\psi\phi$		✓		
x_s	$B_s \to D_s\pi^-$	✓	✓		✓
$\Delta\Gamma$ for B_s	$B_s \to J/\psi\eta'$, K^+K^-, $D_s\pi^-$	✓	✓	✓	✓

Offline Computing Model

- Reuse Level 2/3 trigger farm.
  - 2500-4000 Linux processors
  - Sized to deal with peak lumi.
  - About 2/3 of cycles are available for other uses:
    - Lower lumi late in run.
    - Machine filling, downtime etc
- Use of large computing clusters at universities.
  - Grid aware but not grid dependent.
- See talk by Joel Butler Tuesday afternoon.

Changes in Efficiencies wrt Proposal

- We lost one arm: Factor = 0.5
- We gained on leptons:
  - We now use RICH to improve lepton ID:
    - Larger solid angle; larger momentum range.
  - In proposal we used only $\mu^+\mu^-$, now we include e^+e^-
  - Factor = 2.4 (or 3.9), depending on whether analysis required one or two leptons to be ID'ed.
- DA bandwidth constant for one arm: Factor = 1.15
- For B_s only: improved εD^2: Factor = 1.3

Summary of Efficiency Changes

Mode [Quantity]	Yield in Proposal	Yield Factors	New Yield	New εD^2	Sensitivity	
					Proposal	One Arm
$B^o \to J/\psi\ K_s$ [$\sin(2\beta)$]	80,500	0.5*3.9*1.15=2.24	168,000	0.10	0.025	0.017
$B_s \to J/\psi\eta^{(\prime)}$ [$\sin(2\chi)$]	9,940	0.5*2.4*1.15=1.38	12,600	0.13	0.033	0.024
$B_s \to D_s\ K$ [γ]	13,100	0.5*1.15 =0.58	7,500	0.13	6^o	8^o

- In the proposal all εD^2 were 0.10.